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An examination of land cover and stream water quality among physiographic provinces of Missouri, U.S.A.

Bruce D. Perkins, Kirk Lohman, Erwin Van Nieuwenhuyse and John R. Jones

Introduction

Relations between land cover and stream water quality have been studied within the Ozark Highlands, Ozark Border and Glacial Plains physiographic provinces of Missouri (Fig. 1, LOHMAN 1988, SMART et al. 1985, SKADELAND 1992) and as a part of a larger national survey (OMERNIK 1977). In this paper, we have combined data from the Missouri studies to summarize stream chemistry and draw inferences about land cover-water quality relations. We used data of LOHMAN (1988) in the Ozark Border and Ozark Highlands, VAN NIEUWENHUYSE (1993) in all three physiographic provinces, and a compiled data set from several sources. Based on earlier studies, we hypothesized that agricultural use (increasing row crop with decreasing forest cover) would increase ambient concentrations of total phosphorus (TP), total nitrogen (TN), suspended algal chlorophyll (Chl) and total suspended solids (TSS) in streams. We further hypothesized that the relative influence of pasture and grassland cover on stream water quality will differ between the Ozark Highlands where most land cover is forest, and the Glacial Plains were row crop agriculture is the predominant land cover.

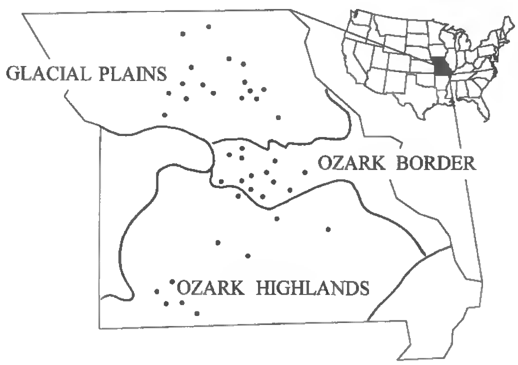

Fig. 1. Map of Missouri showing studied physiographic regions and locations of sample sites.

Methods and site descriptions

Data for this analysis were obtained from stream studies undertaken by the School of Natural Resources, University of Missouri during a 14 year time span. There have been only minor changes in methods for determination of TN, TP, Chl and TSS over this period. Original data can be found in SMART et al. (1985), LOHMAN (1988), SKADELAND (1992), VAN NIEUWENHUYSE (1993), PERKINS & JONES (1994) and CAMPBELL (unpubl.). Inclusion in this assessment required that: 1) catchment areas were greater than 20 km^2; 2) streams were sampled at low to moderate discharge on four or more occasions between March and September; and, 3) there were no impoundments or point sources located upstream. We calculated the geometric mean value for each sampling site.

The three physiographic provinces (Fig. 1) account for 83 % of the surface area of the State of Missouri (THOM & WILSON 1980, JONES & KNOWLTON 1993). Land cover for the watersheds included in this analysis are shown, by physiographic province, in Fig. 2. The Glacial Plains province is based upon Pleistocene deposition with soils composed of glacial loess and till. The Ozark Highlands are unglaciated hills with thin cherty soils, and the Ozark Border is an ecotonal region.

Log_{10} transformed geometric mean values of TN, TP, Chl and TSS were regressed on land cover data to assess patterns. Land cover data was expressed as the arcsin square root of the proportion of land area (OTT 1984) in row crop, pasture (including grassland) and forest within a given watershed (aRC, aP and aF, respectively). Land cover estimates were obtained from Landsat imagery, and catchment areas were calculated by digitizing the boundaries of each watershed.

Results

Stream water chemistry and algal chlorophyll

Consistent with the findings of OMERNIK (1977), stream water chemistry and algal biomass in Missouri shows a strong north-to-south gradient, with values being largest in the Glacial Plains, least in the Ozark Highlands,

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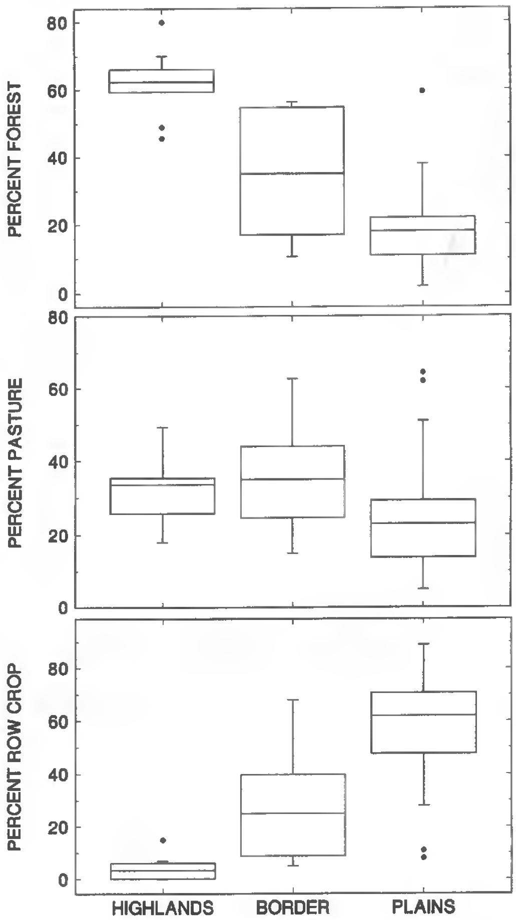

Fig. 2. Box plots of the distribution of land cover types by physiographic province. Box contains 50 % of data points, horizontal line represents median value and vertical (top and bottom) line extends to 1.5 times the interquartile range.

and intermediate in the Ozark Border (Fig. 3). This gradient parallels a gradient in the relative amount of forest cover and row crop on the landscape (Fig 2).

Land cover – water quality relations

In all three data sets, TP, TN, Chl and TSS show strong increases as a function of row crop in the catchment, and parallel decreases with increased forest cover (Figs. 4–7). Among the eight streams within the Ozark Highlands and Ozark Border sampled by Lohman (1988), row crop ranged from 5 to 50 % and forest from 10 to 70 % of the catchment. Water chemistry ranged from 5 to 70 µg/L TP, 150 to 460 µg/L TN, and 0.2 to 12.1 mg/L TSS, with algal Chl values between 0.4 to 13.1 µg/L. Within this data set, row crop accounted for 64 to 88 % of the variation in water quality, and forest accounted for 84 to 88 %. Row crop and forest land accounted for some 55 % of these watersheds. Pasture had the same affect on water quality as row crop and explained a similar amount of the variance. Combining row crop with pasture to represent all agricultural practices in these watersheds explained 10 to 26 % more of the variance in water quality than did either land cover alone (R^2=0.86 to 0.94).

Van Nieuwenhuyse (1993) sampled 12 streams located in all three physiographic regions. His data set had a broad range of land cover; row crop ranged from 4 to 85 % of the catchment and forest from 10 to 70 %. Water chemistry ranged from 10 to 159 µg/L TP, 177 to 802 µg/L TN, and 1.3 to 87.8 mg/L TSS; algal Chl ranged from 1.0 to 39.6 µg/L. Row crop accounted for 72 to 83 % of the variation in water quality and forest accounted for 73 to 75 % (Figs 4–7). Collectively, row crop and forest land accounted for some 78 % of these watersheds. Pasture explained less than a third of the variance in these water quality parameters and when combined with row crop there was no improvement in the models.

The combined data set included 40 sites located in all three physiographic provinces (Fig. 1). Land cover ranged from 4 to circa 85 % for both row crop and forest. Among these streams, TP ranged from 5 to 247 µg/L, TN from 150 to 2664 µg/L, TSS from 0.2 to 92.3 mg/L, and Chl from 0.4 to 39.6 µg/L. Row crop cover accounted for 62 to 83 % and forest cover 49 to 88 % of the variation in water quality; the exception was TN (land cover explained only 10 to 27 %). Weak relations with TN were influenced by five streams in the Ozark Highlands sampled by Smart et al. (1985) with particularly high TN values relative to the others (Fig. 3). This difference may result from regional patterns within the Ozark Highlands (these were the most southerly sites, Fig. 1), and analytical methods may also contribute to this discrepancy. When data of Smart et al. (1985) are eliminated, land cover explains 44 to 58 % of variance in TN.

Overall, land use accounted for less of the variation in water quality in the combined data

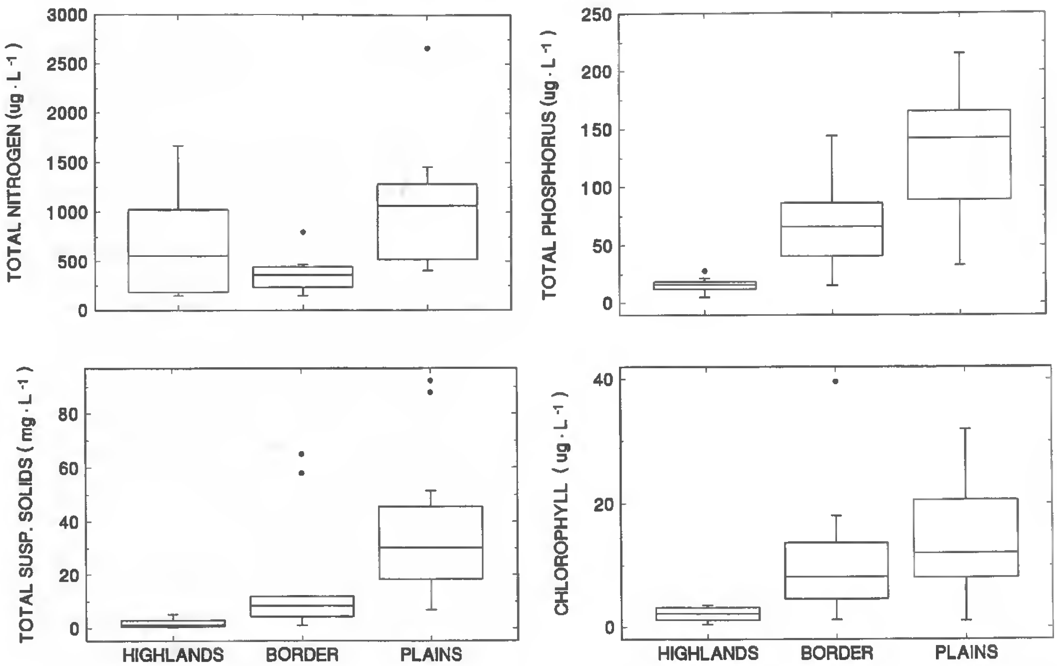

Fig. 3. Box plots of the distribution of water quality variables by physiographic province. Box description as in Fig. 2.

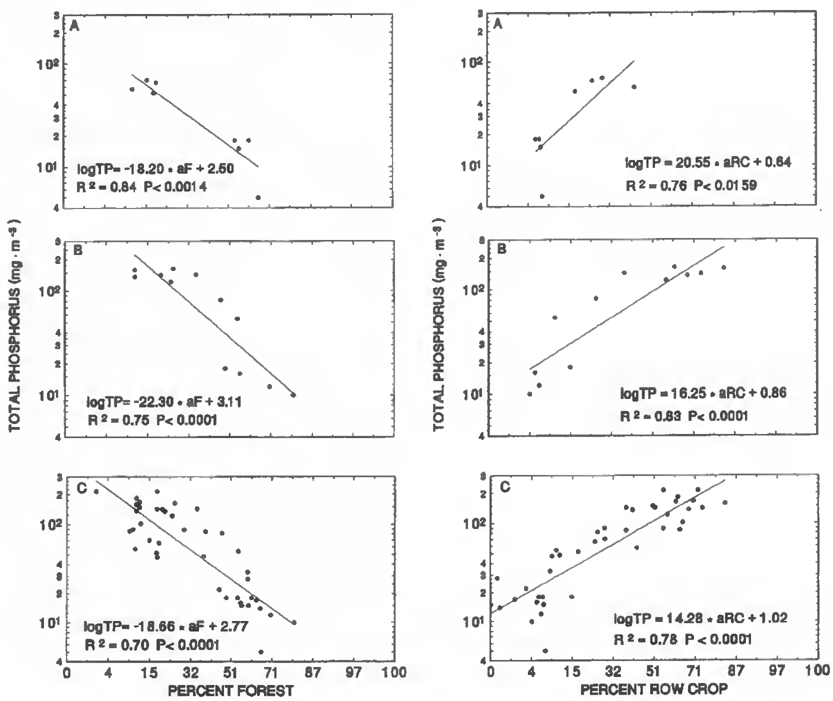

Fig. 4. log transformed TP regressed against arcsin square root transformed row crop and forest proportion (expressed as percent cover) by data set. A, LOHMAN (1988); B, VAN NIEUWENHUYSE (1993); C, combined.

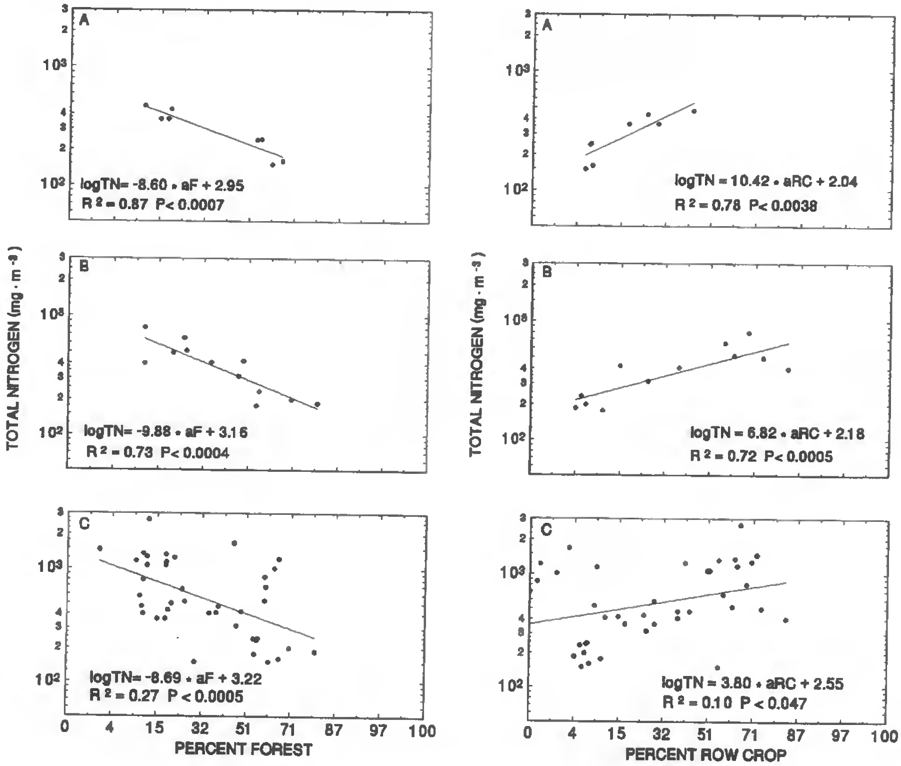

Fig. 5. log transformed TN regressed against arcsin square root transformed row crop and forest proportion (expressed as percent cover) by data set. A, Lohman (1988); B, Van Nieuwenhuyse (1993); C, combined.

set (Figs. 4–7) than in the studies by Lohman (1988) and Van Nieuwenhuyse (1993). Interannual variation may be influencing regressions with the combined data set (which includes data from six separate studies over a 14 year period). Whereas both Lohman and Van Nieuwenhuyse sampled their respective sites within the same season and hydrologic regime. Pasture was weakly correlated with TP in the combined data set and was not significantly related to the other water quality parameters; when combined with row crop there was no appreciable improvement in the models.

Slopes of the regression equations for both row crop and forest cover (Figs. 4–7) did not statistically differ (at the 95 % confidence level) between the data sets of Lohman and Van Nieuwenhuyse (the combined data set was not included in this analysis because it was not independent). This outcome indicates that relations between land cover and stream water chemistry, increasing values with row crop and decreasing values with forest cover, are similar between these data sets and across the physiographic provinces they represent. Because of the nature of these relations (arcsin transformation) the actual change in water quality with a change in land cover in the catchment is not uniform over the range of conditions encountered. Therefore, the effect that a given change in land cover may have on a stream depends on the relative proportion of these land cover types on the watershed (Smart et al. 1985). There were, however, significant differences ($P=<0.01$) in the intercepts of models with forest between the two data sets. Lohman's sites had a narrow range of land cover types and included comparatively dilute streams (lower background) in the Ozark Highland and Ozark Border provinces (Fig. 2).

Effects of pasture on stream water quality

Within the combined data set the distribution of pasture land (mean and range) was similar across all three physiographic provinces (Fig.

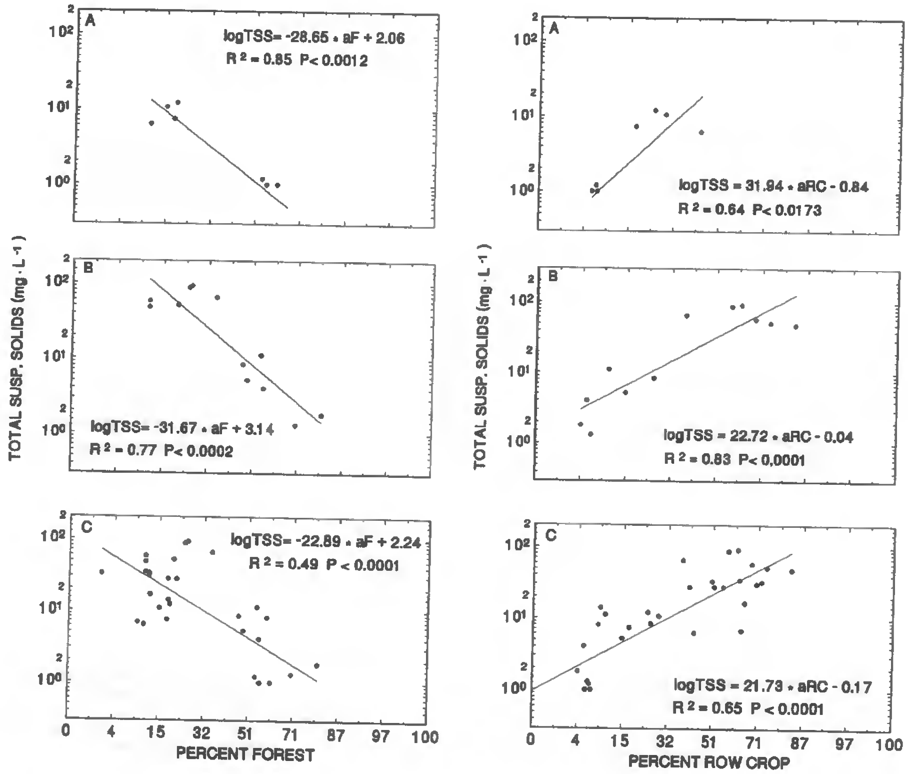

Fig. 6. log transformed TSS regressed against arcsin square root transformed row crop and forest proportion (expressed as percent cover) by data set. A, Lohman (1988); B, Van Nieuwenhuyse (1993); C, combined.

2). However, water quality varied by more than an order of magnitude among streams with near equal proportions of pasture in the catchment (Fig. 8). The general pattern was that values were largest in the Glacial Plains and least in the Ozark Highlands. Among the physiographic provinces, we found large differences in how pasture was related to stream water quality (Table 1). For streams in the Ozark Highlands pasture was positively correlated with each water quality parameter. In the Glacial Plains correlations with pasture were weak and negative with TP, TSS and Chl. And there was no significance with pasture among Ozark Border streams.

This variable effect of pasture seems best explained by how pasture influences water quality relative to other land cover within the watershed and/or province. Within the Ozark Highlands, forest is the predominate land cover (Fig. 2), and relative to forest, pasture is a disturbance on the landscape which increases nutrients, suspended solids and algal levels in streams. This was shown in the empirical models with Lohman's data (Fig. 4–7), correlations in Table 1 and by the work of Smart et al. (1985). Row crop is the predominate land cover in the Glacial Plains (Fig. 2), and within this province an increase in the amount of pasture on the landscape results in improvements in water quality (Table 1). Within the ecotonal province of the Ozark Border, the effect of pasture was not significant within the mix of forest and row crop. This explanation is consistent with Omernik (1977) who found the effects of forest and agriculture masked the effects of cleared unproductive land and wetlands. Omernik (1977) placed cleared unproductive land into a category with forest and wetland types. Beaulac & Reckhow (1982) also found pasture to have low losses of TN and TP relative to other land cover. A factor contributing to this outcome is how pasture land is used – we would expect larger nutrient losses from

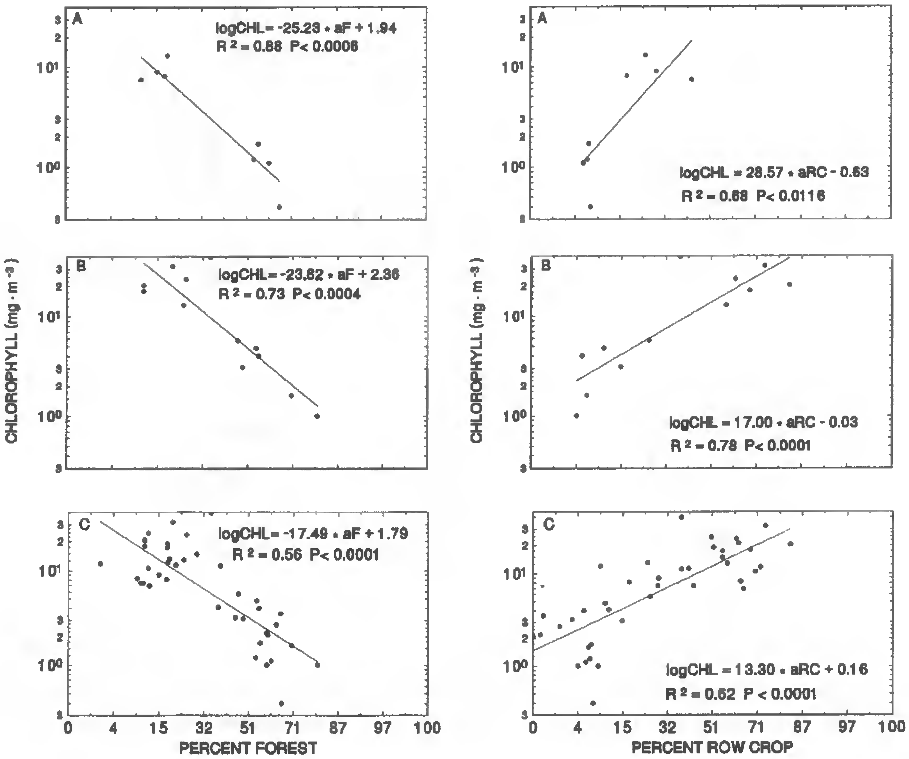

Fig. 7. log transformed CHL regressed against arcsin square root transformed row crop and forest (expressed as percent cover) by data set. A, LOHMAN (1988);, B, VAN NIEUWENHUYSE (1993); C, combined.

Table 1. Correlation coefficient matrix for water quality parameters and arcsin square root transformed land cover by physiographic province (significant at P=0.05).

REGION	UNIT	N	ROW CROP	PASTURE	FOREST	ROW CROP + PASTURE	FOREST + PASTURE
OZARK HIGHLAND	TP	15	N.S.	0.66	-0.55	0.54	N.S.
	TN	15	-0.53	0.79	-0.53	0.54	N.S.
	TSS	10	N.S.	0.72	N.S.	N.S.	N.S.
	CHL	15	N.S.	0.64	-0.54	0.55	N.S.
OZARK BORDER	TP	24	0.86	N.S.	-0.59	0.67	-0.74
	TN	24	0.69	N.S.	-0.74	0.74	-0.66
	TSS	21	0.79	N.S.	-0.52	0.60	-0.69
	CHL	24	0.79	N.S.	-0.59	0.70	-0.66
GLACIAL PLAINS	TP	21	0.87	-0.56	-0.60	0.68	-0.79
	TN	21	N.S.	N.S.	-0.44	N.S.	N.S.
	TSS	19	0.53	-0.62	N.S.	N.S.	-0.48
	CHL	21	0.60	-0.61	N.S.	N.S.	-0.59

fertilized and grazed pastures than from fallow grasslands. Differentiating these effects, however, was outside the scope of this study.

Discussion

This empirical analysis shows strong relations between stream water quality and land cover across three major physiographic provinces of Missouri. Land cover accounts for a large amount of the variance in stream water quality in systems not influenced by effluents or impoundments. The general pattern is for water chemistry and algal biomass to increase with the amount of row crop and decline with forest cover (Figs. 4–7). The main effect of pasture land on stream water quality in Missouri is relative to the predominate land cover and degree of disturbance in the region (Table 1, Fig. 8). An appropriate study would be to measure and compare loss of nutrients and solids from managed and fallow pastures located within each physiographic provinces. These data would provide a direct assessment of how pastures affect stream water quality throughout the state.

By the nature of the assessment, comparative studies of land cover and water quality are best

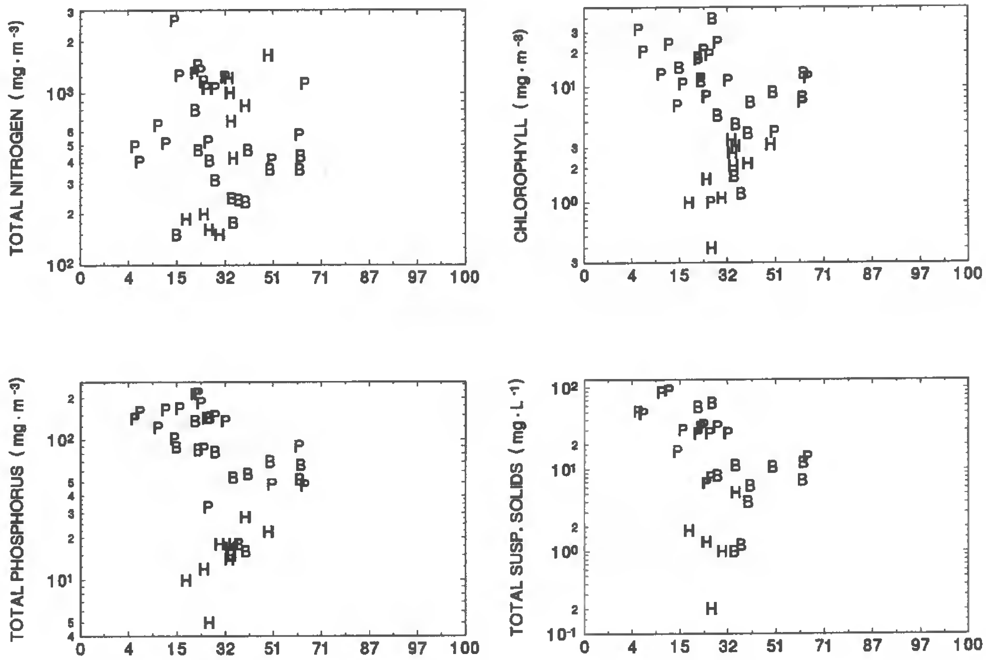

Fig. 8. Water quality parameters and arcsin square root transformed pasture proportion relations (expressed as percent pasture). Symbols represent physiographic region. H-Ozark Highlands, B-Ozark Border, P-Glacial Plains.

limited to specific regions and the results greatly depend on the mix of land cover within an area. Researchers have generally found higher nutrients in agricultural watersheds than forested ones (OMERNIK 1977, OSTRY et al. 1982, CLESCERI et al. 1986 and others). But within agricultural regions it has not always been possible to identify how specific land cover practices influence non-point water quality. The data of SKADELAND (1992) from sites in a single river basin in the Glacial Plains showed weak relations with land cover but strong correlations with catchment area. In a study of streams in an intensive agricultural region in northern Iowa, JONES et al. (1976) found nitrate negatively correlated with wetlands and phosphorus positively correlated with animal units in feedlots but expected relations between nutrients and row crop were not detected. Collectively, literature on this topic supports the approach of regional studies of how land cover influences non-point stream water quality.

Acknowledgements

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Authors' address:

B. D. PERKINS, K. LOHMAN, E. VAN NIEUWENHUYSE and J. R. JONES, School of Natural Resources, Fisheries and Wildlife, University of Missouri, Columbia, MO 65 211, USA.